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THESIS

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ON RESPONSE TIMES UNDER UNCERTAINTY

by

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by

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ABSTRACT

A preliminary investigation of the effect of actual motion distances on response times under uncertainty was performed. An experiment in which three subjects were presented with five levels of choice uncertainty and three simulated control panel configurations was conducted. Results indicated variations in response times attributable to changes in motion distance at the five percent level of significance. Explanatory models are proposed. Recommendations for future study are given.

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I. INTRODUCTION

A. PURPOSE

In recent years, a significant amount of research has been conducted concerning human responses to imposed stimuli. The end objective of these efforts would seem to be increased understanding of human operator performance and development of accurate relationships between measures of human performance and specific tasks. This paper is directed toward one such relationship concerning hand motion distance.

Most current practices in systems design and evaluation appear to be based on a direct response hypothesis. It is assumed that, in response to a stimulus, an operator's hand motion traces a direct path to the required response position from the terminal position of the preceding motion. While there is evidence that conflicts with this practice, the lack of adequate descriptive models for hand motion leaves no alternative.

It was the purpose of this thesis to conduct a preliminary examination of the effect of varying motion strategies on movement times and to propose some basic explanatory models.

B. BACKGROUND

Several efforts have been directed toward measuring human information capacity and response ranges. Rubin, et. al. (1952), investigated motion paths over a simulated control surface and found that motion complexity had very little to do with response speed. Performance in tasks which varied information through changing the number of alternative choices, probabilities of occurrence and sequential dependencies among the stimulus set was studied by Hyman (1953). He found a linear relationship

between reaction time and information, in bits, as quantified by Shannon's information metric, Shannon (1969) more properly called entropy given by:

$$h(p) = -\sum_j p_j \log_2 p_j \tag{1}$$

where p_j are the probabilities associated with the alternatives in the stimulus set.

Attempts to quantify this relationship have resulted in numerous descriptive models for movement time. Simon and Smader (1955) reported that the necessity to discriminate between stimuli during hand motion increased motion times and noted that industrial methods of motion prediction did not address that phenomenon. Fitts (1954) showed that movement times increase in proportion to the index of difficulty defined as:

$$ID = \log_2 \frac{2_A}{W} \tag{2}$$

where A is the required amplitude of motion and W is the circular error tolerance.

In 1970, Kuttan and Robinson showed that first order models were appropriate but imperfect descriptors of response hand motion. The relationship borne out involved this index and other previous models. A model which related movement time to the required direction of motion as well as to this index was offered by Scholes (1970). Fitts, Peterson and Wolpe (1963) demonstrated that the ability to process a signal improves slowly as the subject gains familiarity with the task. A second important result of their work was that the linear relationship between entropy and response times did not hold at the extremes of uncertainty for individual component events (individual stimuli). They noted that both the most frequent and least frequent events were responded to more rapidly than predicted and observed that no general formulation had been presented

to handle these departures. Other factors affecting the slope of this line were found by Fitts and Peterson (1964).

More recent efforts, directed toward sequential and/or prediction outcome effects on response times, show evidence that the reaction time on trial N may be influenced by the sequence of trials as far back as trial N-5 (Hale, 1970), (Remington, 1969). Peeke and Stone (1972), however, offer evidence that the added difficulty in dealing with an increased number of alternatives may interfere with a subject's ability to retain and profit from the occurrance of events farther back in time than N-1. Whitman and Geller (1971) demonstrated that response times were significantly faster not only to repeated events as shown by Bertelson (1963) but also following runs of correct predictions. Other investigators such as Remington (1971), Hale (1967) and Bertelson (1961) extended the overall understanding of the repetition effect. The dependence of response times to both repeated and non-repeated stimuli on the length of the response-stimulus interval has been demonstrated by Umilta, et. al. (1972). An examination of their data which reveals error rates averaging 20 percent for low probabilities and only 0.4 percent for high probabilities would seem to indicate a significant number of premature incorrect responses. This result was not addressed by the authors but might be explained by Hawkins, et. a.'s (1970) premature response hypothesis. They indicated that, with a large response bias, a subject would make a significant number of premature fast response decisions favoring the most likely response. This would necessarily lead to a greater proportion of long movement times associated with uncommitted errors. Blackman (1972) points out that this would result in increased mean response times due to a number of long movement times to low frequency stimuli. It would also seem to explain a higher error rate for low frequency stimuli.

The belief that an operator's performance is influenced by his perception of the stimulus set was supported by Thomas (1973). He indicated that operators have been found to employ motion strategies, apparently based on the most frequently required response alternatives, to accommodate the uncertainty. As this would obviously influence motion distances and could have an effect on response times, he suggested that, in the interest of safety and/or efficiency, it might be desirable to relocate response media for some operations.

C. OBJECTIVE

The objective of this investigation was to demonstrate that variations in response times can be explained in part by variations in motion strategies and to lend support to the belief that further research should be conducted concerning actual hand motion distance over a control surface.

D. SCOPE

An experiment designed to test the hypothesis that a subject's motion strategies affect response times is described in section II. Proposed explanatory models are given in section III. A general discussion and recommendations for future study are given in section IV.

II. THE EXPERIMENT

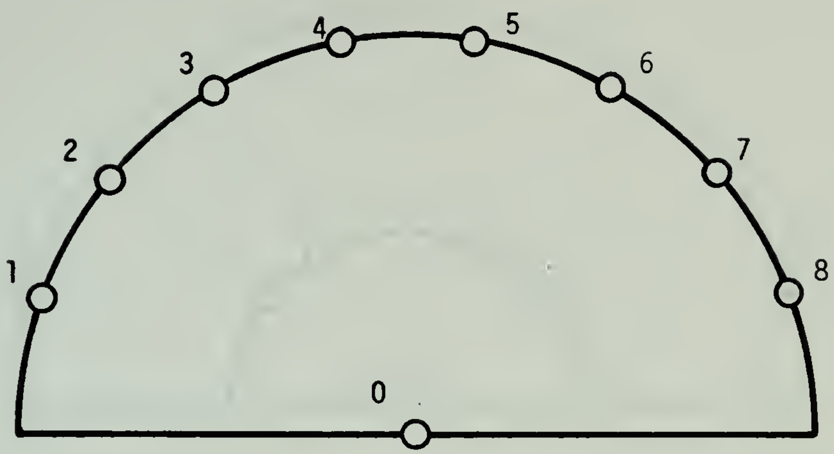
A. THE TASK

In this study the laboratory task was similar to that used by Stewart (1973). The design of the logic circuitry constructed for the collection of response time data was identical to that used in the Stewart experiment and is extensively analyzed in that work.

The experiment presented subjects with a manual-decision task through the use of a button board located in a sound isolation room. The board consisted of eight response buttons, which could be relocated to any desired configuration and a base or zero button used to initiate each cycle. For this experiment, the buttons were arranged and numbered as in Figures 1, 2 and 3.

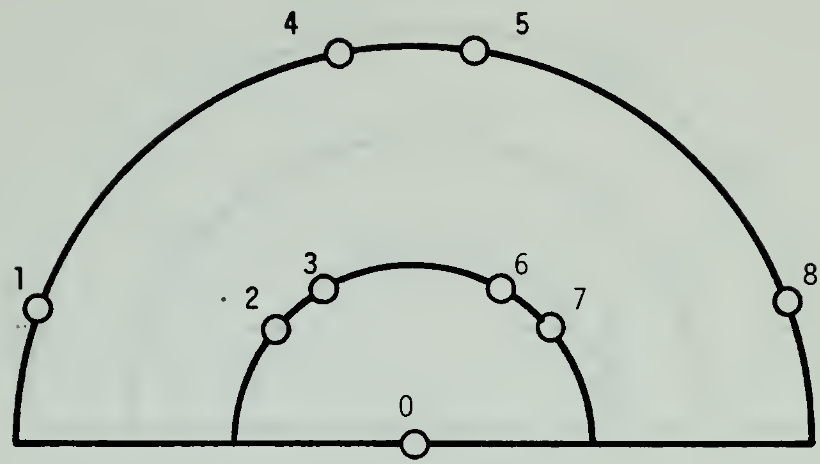
A stimulus was presented by a seven segment digital readout located at the top center of the board. Distribution of stimulus and response signals was accomplished through the use of a logic circuit. A pulse from the base button or any of the response buttons caused a paper tape reader to step. The binary code from the tape reader was decoded to provide the stimulus. The subject would initiate a cycle by depressing the base button. This would step the tape reader to provide the stimulus and provide an "initiate" signal to the computer. The subject would then proceed to a response button. Depression of that button would step the tape reader to a zero indication and provide a "stop" signal to the computer, completing the cycle. The zero display was used as a feedback item to indicate cycle completion and was considered to provide no information relative to the task.

FIGURE 1. Panel Configuration 1



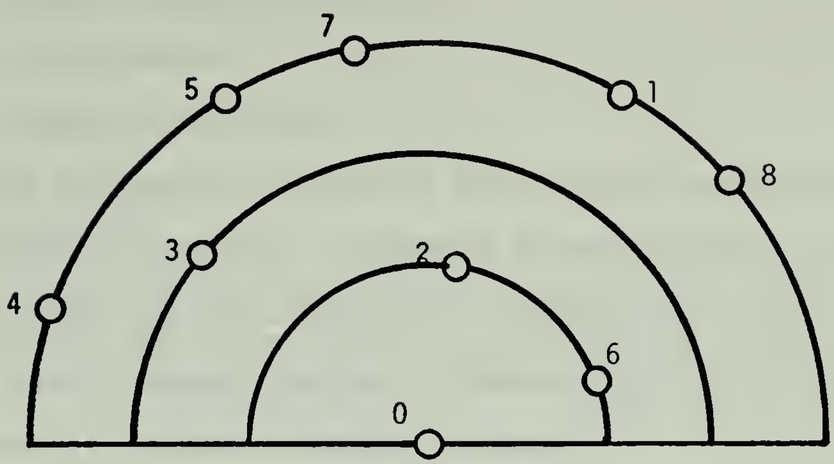
	BASE	1	2	3	4	5	6	7	8
BASE	0	11	11	11	11	11	11	11	11
1	11	0	3.9	7.5	11	14.1	16.9	19.1	20.7
2	11	3.9	0	3.9	7.5	11	14.1	16.9	19.1
3	11	7.5	3.9	0	3.9	7.5	11	14.1	16.9
4	11	11	7.5	3.9	0	3.9	7.5	11	14.1
5	11	14.1	11	7.5	3.9	0	3.9	7.5	11
6	11	16.9	14.1	11	7.5	3.9	0	3.9	7.5
7	11	19.1	16.9	14.1	11	7.5	3.9	0	3.9
8	11	20.7	19.1	16.9	14.1	11	7.5	3.9	0

FIGURE 2. Panel Configuration 2



	BASE	1	2	3	4	5	6	7	8
BASE	0	11	5	5	11	11	5	5	11
1	11	0	6.5	7.9	11	14.1	12.9	14.2	20.7
2	5	6.5	0	1.7	7.9	9.5	6.4	7.7	14.2
3	5	7.9	1.7	0	6.5	7.9	5	6.4	12.9
4	11	11	7.9	6.5	0	3.8	7.9	9.5	14.1
5	11	14.1	9.5	7.9	3.8	0	6.5	7.9	11
6	5	12.9	6.4	5	7.9	6.5	0	1.7	7.9
7	5	14.2	7.7	6.4	9.5	7.9	1.7	0	6.5
8	11	20.7	14.2	12.9	14.1	11	7.9	6.5	0

FIGURE 3. Panel Configuration 3



	BASE	1	2	3	4	5	6	7	8
BASE	0	11	5	8	11	11	5	11	11
1	11	0	6.5	12.4	16.9	11	7.9	7.5	3.8
2	5	6.5	0	7	11.3	7.9	5	6.5	7.9
3	8	12.4	7	0	4.4	4.4	11.4	7.1	14.7
4	11	16.9	11.3	4.4	0	7.5	15.2	11	19.1
5	11	11	7.9	4.4	7.5	0	12.9	3.8	14.1
6	5	7.9	5	11.4	15.2	12.9	0	11.3	6.5
7	11	7.5	6.5	7.1	11	3.8	11.3	0	11
8	11	3.8	7.9	14.7	19.1	14.1	6.5	11	0

Available logic circuitry provided the following functions:

a. response indication

b. correct response indication

c. camera control

d. response time signals

It was believed that presenting subjects with manual-decision tasks of varying mean distances, at different levels of entropy, would result in significant variations across mean distances that could not be explained by a direct response hypothesis. Models could then be presented which would serve to explain the results obtained.

B. EXPERIMENTAL DESIGN

The experimental design model was a randomized block factorial design with each subject receiving all treatment combinations in order to eliminate subject variability effects from masking treatment effects. The two factors were:

1. probability distributions P: 5 levels

2. mean distances B: 3 levels

Thus giving 15 treatment combinations. The fixed effects linear model for this design is:

$$X_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijk} \tag{3}$$

where μ = the overall mean

α_i = effect due to Factor P

β_j = effect due to Factor B

$\alpha\beta_{ij}$ = row column interaction effects

ε_{ijk} = error

400 response times per subject per treatment combination provided the necessary replications to separate $\alpha\beta_{ij}$ and ε_{ijk}.

C. SUBJECTS

Subjects for the experiment were 3 volunteers, 2 male and 1 female, between 26-32 years of age, with no known mental or physical disorders.

Results pertaining to a particular subject are indicated by S1, S2 or S3 where required.

D. PROCEDURES

The methods given in the computer programs section of this paper were used to generate 5 tapes of 490 integers each followed by a zero. The entropy associated with the probability distribution of the eight integers on each tape was computed by equation (1). These are given in Table I along with the 5 probability distributions selected as levels of factor "P."

Button panel configurations were selected to provide 3 levels of mean distance as shown by Figures 1, 2 and 3 along with the distances among buttons for each level of factor "B."

Each subject received all treatment combinations, assigned randomly, over a one day period. As each string of 490 numbers required a minimum of 20 minutes to complete, the collection of data for each individual was a somewhat lengthy process and it was believed that, by randomizing the presentation order, one could minimize the effects of fatigue, boredom and learning on the results.

Subjects were instructed to minimize response times and errors and, as the experiment was self-paced once initiated, were allowed to rest when desired.

In order to sample actual motion distances and provide a means of measurement, a motion picture camera mounted above the button board was utilized to photograph trials 350-375 for each treatment combination.

TABLE I

ENTROPY OF THE STIMULUS SETS

TAPE	STIMULUS PROBABILITIES (p_i)								H(p)
	1	2	3	4	5	6	7	8	
P1	.125	.125	.125	.125	.125	.125	.125	.125	3.00 2.999*
P2	.053	.340	.053	.053	.053	.340	.053	.053	2.411 2.407*
P3	.083	.083	.083	.083	.250	.250	.083	.083	2.792 2.789*
P4	.060	.060	.300	.060	.300	.060	.060	.100	2.592 2.582*
P5	.071	.071	.071	.071	.071	.071	.500	.071	2.404 2.404*

* Based on relative frequency of occurrence

The procedure, unfortunately, did not provide the desired results. Although the equipment operated in a satisfactory manner, the lighting conditions were miscalculated to such an extent that only a bare minimum of information was obtained from the resulting films and that only through extensive analysis.

Error responses were recorded on a 2-channel brush recorder which received a pulse on channel 1 for any response and on channel 2 only if the response was correct.

At the completion of each 490 number string, the computer provided a paper tape of 490 response times for further analysis. The methods used in selecting 400 error free responses from these tapes is given in the computer programs section.

E. RESULTS AND CONCLUSIONS

1. Results

Error responses over all treatment combinations for all subjects averaged 1.52 percent. A summary of total error responses over 490 trials per treatment combinations is given by Table II. Nonparametric Freedman two way analysis of variance tests performed on this data indicated that panel configurations, probability distributions or particular treatment combinations could not be assumed to have an effect on the number of errors at the 5 percent level of significance.

Mean response times over 400 error free responses for each subject at each treatment combination are given by Tables III, IV and V. The ANOVA in each case (see Table VI) indicated that both factors were significant at the 5 percent level and that there were significant interactions present. These interactions were assumed to be due to learning and other effects beyond experimental control and were not treated further.

TABLE II

SUMMARY OF ERROR RESPONSES

	B1	B2	B3
	S1 = 11	S1 = 11	S1 = 13
P1	S2 = 17	S2 = 11	S2 = 3
	S3 = 7	S3 = 2	S3 = 2
	S1 = 7	S1 = 9	S1 = 8
P2	S2 = 11	S2 = 8	S2 = 5
	S3 = 3	S3 = ∅	S3 = 5
	S1 = 1∅	S1 = 13	S1 = 15
P3	S2 = 16	S2 = 9	S2 = 5
	S3 = 2	S3 = 4	S3 = 2
	S1 = 1∅	S1 = 6	S1 = 12
P4	S2 = 1∅	S2 = 6	S2 = 1∅
	S3 = 3	S3 = ∅	S3 = 1
	S1 = 15	S1 = 11	S1 = 9
P5	S2 = 16	S2 = 7	S2 = 4
	S3 = 4	S3 = ∅	S3 = 2

ERROR RESPONSES AVERAGED 1.52 PERCENT

TABLE III

MEAN RESPONSE TIME SUMMARY

FOR SUBJECT ONE

	B1	B2	B3	
P1	.872 309.492 .014 14	.864 308.560 .025 13	.881 327.025 .042 15	$\bar{y}_{1..}$=.872
P2	.793 258.817 .018 9	.758 243.479 .034 5	.683 200.663 .035 1	$\bar{y}_{2..}$=.745
P3	.795 258.304 .014 10	.828 284.479 .026 12	.827 283.961 .026 11	$\bar{y}_{3..}$=.817
P4	.768 245.095 .024 6	.780 255.494 .031 8	.770 251.963 .037 7	$\bar{y}_{4..}$=.773
P5	.718 220.808 .037 3	.714 223.763 .050 2	.723 224.009 .037 4	$\bar{y}_{5..}$=.718
	$\bar{y}_{.1.}$= .789	$\bar{y}_{.2.}$= .789	$\bar{y}_{.3.}$= .777	$\bar{y}_{...}$= .785
mean sumsq var rank		n=400		

TABLE IV

MEAN RESPONSE TIME SUMMARY

FOR SUBJECT TWO

	B1	B2	B3	
P1	.922 349.362 .023 12	.924 350.760 .022 13	1.015 429.534 .043 15	$\bar{y}_{1..}=.954$
P2	.836 286.567 .017 7	.824 281.465 .024 4	.850 299.028 .024 9	$\bar{y}_{2..}=.837$
P3	.821 275.974 .017 3	.885 322.679 .024 10	.895 328.808 .020 11	$\bar{y}_{3..}=.867$
P4	.825 280.398 .021 5	.834 285.235 .018 6	.929 357.883 .032 14	$\bar{y}_{4..}=.863$
P5	.773 251.881 .032 1.5	.773 257.519 .046 1.5	.843 310.029 .065 8	$\bar{y}_{5..}=.796$
	$\bar{y}_{.1.}=$ .835	$\bar{y}_{.2.}=$ .848	$\bar{y}_{.3.}=$ .906	$y_{...}=$ .863

mean
sumsq
var
rank

n=400

TABLE V

MEAN RESPONSE TIME SUMMARY

FOR SUBJECT THREE

	B1	B2	B3	
P1	.922 345.597 .014 12	1.009 414.35 .018 15	.957 382.827 .042 14	$\bar{y}_{1..}$=.963
P2	.849 295.138 .017 9	.943 360.375 .012 13	.785 263.760 .044 2	$\bar{y}_{2..}$=.859
P3	.831 284.648 .021 8	.824 276.055 .011 7	.912 343.094 .027 11	$\bar{y}_{3..}$=.856
P4	.805 274.154 .037 5	.816 270.331 .010 6	.901 332.540 .020 10	$\bar{y}_{4..}$=.841
P5	.793 272.752 .053 3	.799 273.394 .044 4	.799 255.563 .032 1	$\bar{y}_{5..}$=.790
	$\bar{y}_{.1.}$= .84	$\bar{y}_{.2.}$= .878	$\bar{y}_{.3.}$= .867	$\bar{y}_{...}$= .862

mean
sumsq
var
rank

n=400

TABLE VI. ANOVA

SUBJECT 1				
SOURCE	SS	DF	MS	F
GENERAL MEAN	3697.35	1		
DISTRIBUTIONS	17.76	4	4.44	149.49*
PANELS	.19	2	.10	3.23*
INTERACTION	2.72	8	.34	11.33*
ERROR	177.72	5985	.03	
TOTAL	3895.74	6000		

SUBJECT 2				
SOURCE	SS	DF	MS	F
GENERAL MEAN	4468.61	1		
DISTRIBUTIONS	16.15	4	4.04	139.24*
PANELS	5.72	2	2.86	98.55*
INTERACTION	1.91	8	.24	8.22*
ERROR	174.75	5985	.03	
TOTAL	4667.12	6000		

SUBJECT 3				
SOURCE	SS	DF	MS	F
GENERAL MEAN	4458.26	1		
DISTRIBUTIONS	19.05	4	4.76	183.08*
PANELS	1.53	2	.77	29.42*
INTERACTION	9.25	8	1.16	44.62*
ERROR	156.48	5985	.03	
TOTAL	4644.58	6000		

* $P < .05$

A Duncan multiple range test, conducted on the data for each subject, indicated a somewhat higher degree of consistancy between subjects than it had at first appeared. The results of these tests, given in Table VII, revealed that only a few treatment combinations resulted in differences that could not be shown to be significant at the 1 percent level. The results of this test suggested also a possibility that differences across the levels of factor "B" had a tendency to diminish at lower levels of entropy.

If one attempts to explain the results obtained with a direct response hypothesis, he must assume that response times will vary directly with distance. In other words, the perceptual, cognitive and sensory processes for a fully learned subject would contribute a relatively constant effect, for an identical number of alternatives, and any variation in time would be due to movement time. Equation (2) indicates that this must be assumed to vary directly with the amplitude of the response. If this is the case, one would expect a high degree of correlation between the mean Euclidean distance for treatment combinations and the corresponding mean reaction times obtained. This is definitely not the case for the data obtained. Ranking both mean response times and mean Euclidean distances from smallest to largest, Spearman rank correlation coefficients were computed for the 3 subjects with the following results:

S1: $r_s = .22$

S2: $r_s = -.017$

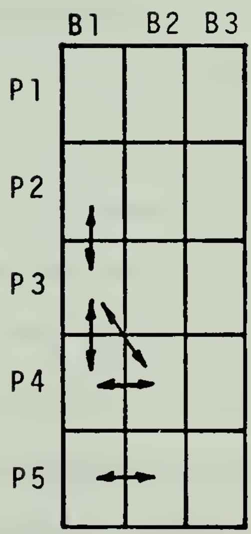
S3: $r_s = -.026$

Scholes (1970) demonstrated that movement time was related to the required direction of response as well as Fitts' index of difficulty. Using a task similar to the one in this study, he derived the regression model for movement time given by:

TABLE VII

DUNCAN MULTIPLE RANGE TEST SUMMARY

	P1 B1	P2 B1	P3 B1	P4 B1	P5 B1	P1 B2	P2 B2	P3 B2	P4 B2	P5 B2	P1 B3	P2 B3	P3 B3	P4 B3	P5 B3
P1B1		1 2 3	1 2 3	1 2 3	1 2 3	3	1 2	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2	1	1 2 3
P2B1				3	1 2 3	1 2 3	1 3	1 2	3	1 2 3	1 2 3	1 3	1 2 3	2 3	1 3
P3B1					11 2	1 2 3	1 3	1 2		1 2	1 2 3	1 3	1 2 3	2 3	1 3
P4B1					1 2	1 2 3	3	1 2		1 2	1 2 3	1	1 2 3	2 3	1
P5B1						1 2 3	1 2 3	1 2	1 2		1 2 3	2	1 2 3	1 2 3	2
P1B2							1 2 3	1 2 3	1 2 3	1 2 3	2 3	1 2 3	1 3	1 3	1 2 3
P2B2								1 2 3	3	1 2 3	1 2	1 3	1 2 3	2 3	1 3
P3B2									1 2	1 2	1 2 3	1 2 3	3	1 2 3	1 2 3
P4B2										1 2	1 2 3	1	1 2 3	2 3	1 3
P5B2											1 2 3	2	1 2 3	1 2 3	2
P1B3												1 2 3	1 2 3	1 2 3	1 2 3
P2B3													1 2 3	1 2 3	1
P3B3														1 2	1 2 3
P4B3															1 2 3
P5B3															



non-significant differences

Entry indicates significant difference for subject

$$MT = -27+98\ ID - 20(SIN\ X) \quad (4)$$

where X was the required direction of motion measured in degrees from a horizontal line through the base response. Mean Euclidean distances and directions, and a button diameter of one inch were used to derive an expected motion time for each treatment combination. These were again ranked and compared to the data for each subject. The resulting Spearman rank correlations obtained with this procedure were:

S1: $r_s = .127$

S2: $r_s = .133$

S3: $r_s = .167$

Scholes' model was not considered adequate to explain the results obtained in this study. It should be noted, however, that the model was derived under conditions of certainty and the fact that it provides low correlation with the results in this study is inconclusive. The model does provide consistent results across subjects and is believed to have some merit. Table VIII summarizes the mean Euclidean distances and directions for treatment combinations as well as the expected motion, times from Scholes' model.

It was not an original purpose of this paper to examine the effect of the various levels of mean distance on the slope of the line relating entropy to response times. It was interesting to note, however, that when mean response times were regressed against entropy, for each level of distance, the data for all subjects demonstrated a consistent effect on the slope of the line. Figure 4 shows the results when mean responses across all subjects were used in the regression. The results for individual subjects demonstrated the same effect. It must be realized, of course, that the regressions are based on only 5 points, of minimal

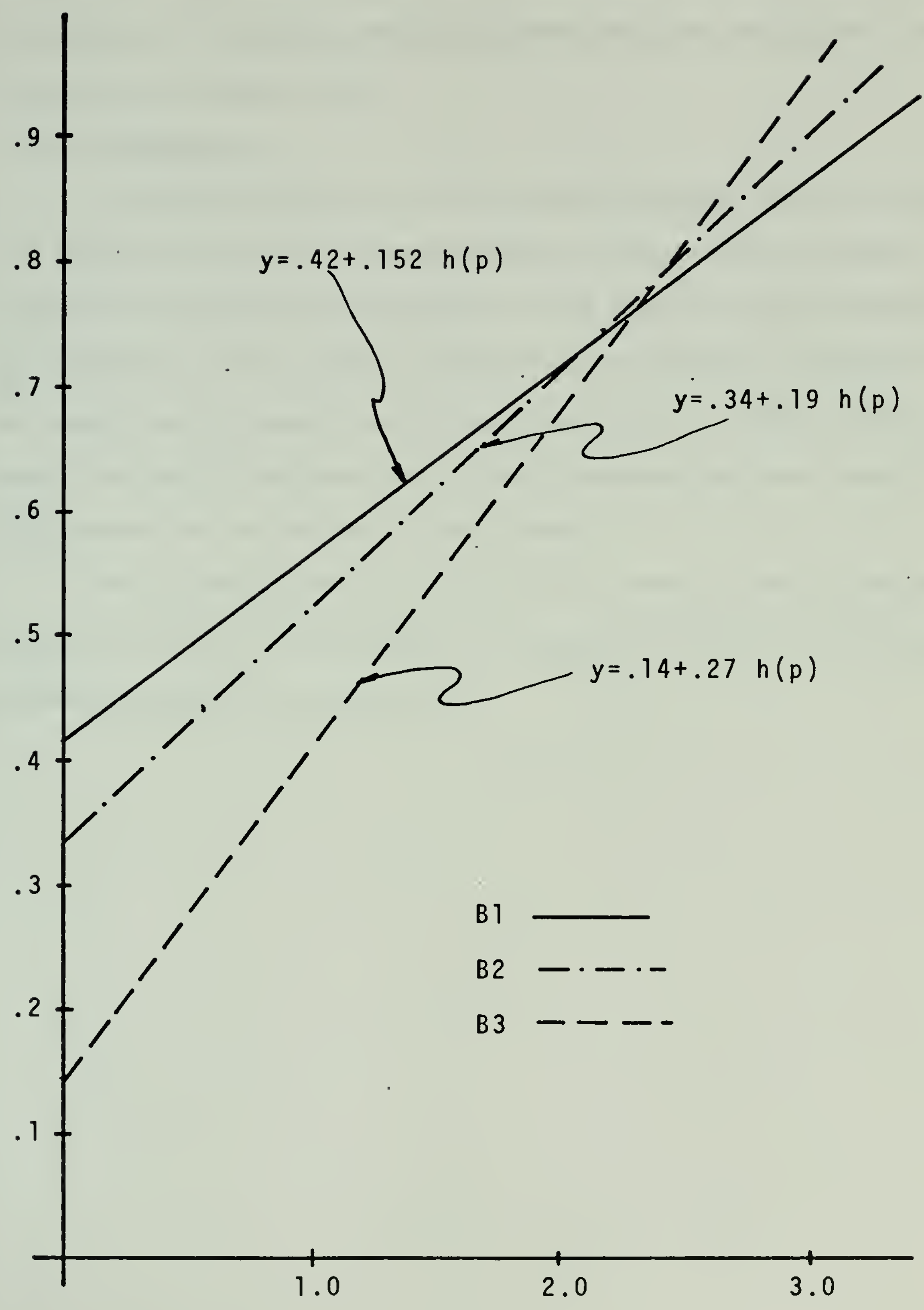
TABLE VIII

EXPECTED EUCLIDEAN DISTANCES, DIRECTIONS AND EXPECTED MOTION TIMES FOR A DIRECT RESPONSE HYPOTHESIS

	B1	B2	B3
	11	8	9.13
P1	90	90	90
	389.98	345	363.72
	11	6.28	6.76
P2	84.25	84.25	112.92
	390.08	310.9	322.77
	11	8	8.75
P3	96.65	96.65	96.65
	390.13	345.15	357.79
	11	8.12	9.38
P4	88	88	72.8
	390	247.07	368.43
	11	6.71	9.93
P5	111.41	111.41	85.7
	391.34	321.47	375.64

E (d) distance in inches
E (θ) θ in degrees
E (mt) mt in milliseconds

FIGURE 4. Regression Lines



separation, and as this can certainly not be considered conclusive.

Also of interest was the fact that the data for all subjects provided significant differences for distributions number 5 and number 2 in all cases. These distributions are at equivalent entropy levels (2.40 vs. 2.41) and, if a linear model is appropriate, they should have resulted in equivalent response times.

2. Conclusions

The results obtained in this experiment suggest that there may be a substantial change in response times over a given control panel configuration which can be attributed to the motion strategy employed by the operators. Fully learned operators may use programmed movements that are significantly larger than one might expect from a direct motion analysis. The results indicate that a direct response hypothesis might be insufficient for the analysis of hand motion.

The following section will attempt to provide other explanatory models which should be considered in attempting to derive a satisfactory mathematical model for hand motion.

III. PROPOSED MODELS

The proposed models assume that under uncertainty a subject will adopt a strategy based on his perception of the stimulus set which will serve to accommodate the uncertainty. It is postulated that in response to stimuli a subject will initiate motion toward a perceived most likely response. Observation of the small amount of motion photography obtained indicated that when a subject initiated motion toward a target response, he seldom completed that motion prior to moving to the required response. The models must therefore reflect the magnitude of the pre-stimulus motion.

Figure 5 illustrates distance relationships from an initial position zero to a required response j via the target response i.

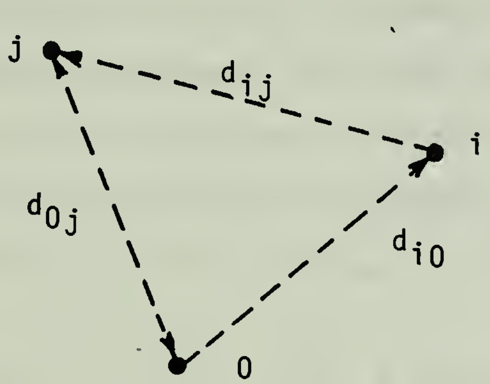


FIGURE 5. Distance Relationships

One may show, using relationships that hold for any plane triangle, that, for a motion short or long of the initial target, the total motion distance is given by:

$$\frac{d_{io}}{N} + \sqrt{\frac{d_{ij}^{2} + (N-1)\left(d_{oj}^{2} - \frac{d_{io}^{2}}{N}\right)}{N}}$$

where N is the factor by which the motion toward the initial target has changed; e.g., if $N = 2$, then; $d_{10}/2$ = magnitude of pre-stimulus motion. This procedure allows one to obtain the expected motion distance for any given strategy in terms of the assumed pre-stimulus motion.

In the following models, the total motion distance to response j given initial motion toward response i and a factor "N" is represented by: $(d_j \mid i, N)$

A. MOST PROBABLE RESPONSE MODEL

This model assumes that the subjects perceived most likely response will be the most likely alternative or set of alternatives in the stimulus set. It further assumes that initial responses to stimuli in the most probable set will be in proportion to their probability of occurrence. This may, in fact, not be the case as a subject may have a preference for a particular alternative in the set. The model, however, was considered adequate for initial investigation. This model with one alternative in the most probable set was investigated by Stewart (1973). If a subject was assumed to employ this strategy, the expected distance for a particular treatment combination would be written:

$$E(d \mid s_i) = \sum_j P_j \sum_{k \in \omega} \frac{P_k}{\sum_{l \in \omega} P_l} (d_j \mid k, N) \tag{5}$$

where ω is the set of most probable responses for a given value of N.

B. PREVIOUS RESPONSE MODEL

This model assumes that the subjects perceived most likely response will be the alternative that appeared on the immediately preceding trial. This implies that his initial motion on trial N would be to the response required on trial N-1. The expected motion distance in this case would be written:

$$E(d \mid s2) = \sum_j P_j \left[\sum_i P_i \, (d_j \mid i, N) \right] \tag{6}$$

C. PREVIOUS TWO RESPONSES MODEL

This model assumes that a subject will initiate motion toward a response only if the previous two responses were to that alternative. He would otherwise proceed directly toward the required response with no prestimulus motion. The expected distance in this case would be written:

$$E(d \mid s3) = \sum_j P_j \left[\sum_i \frac{P_i^2}{1-P_i} (d_j \mid i, N) + \left(1 - \sum_i \frac{P_i^2}{1-P_i}\right) d_{oj} \right]$$

where the probability of two previous responses to i is given by:

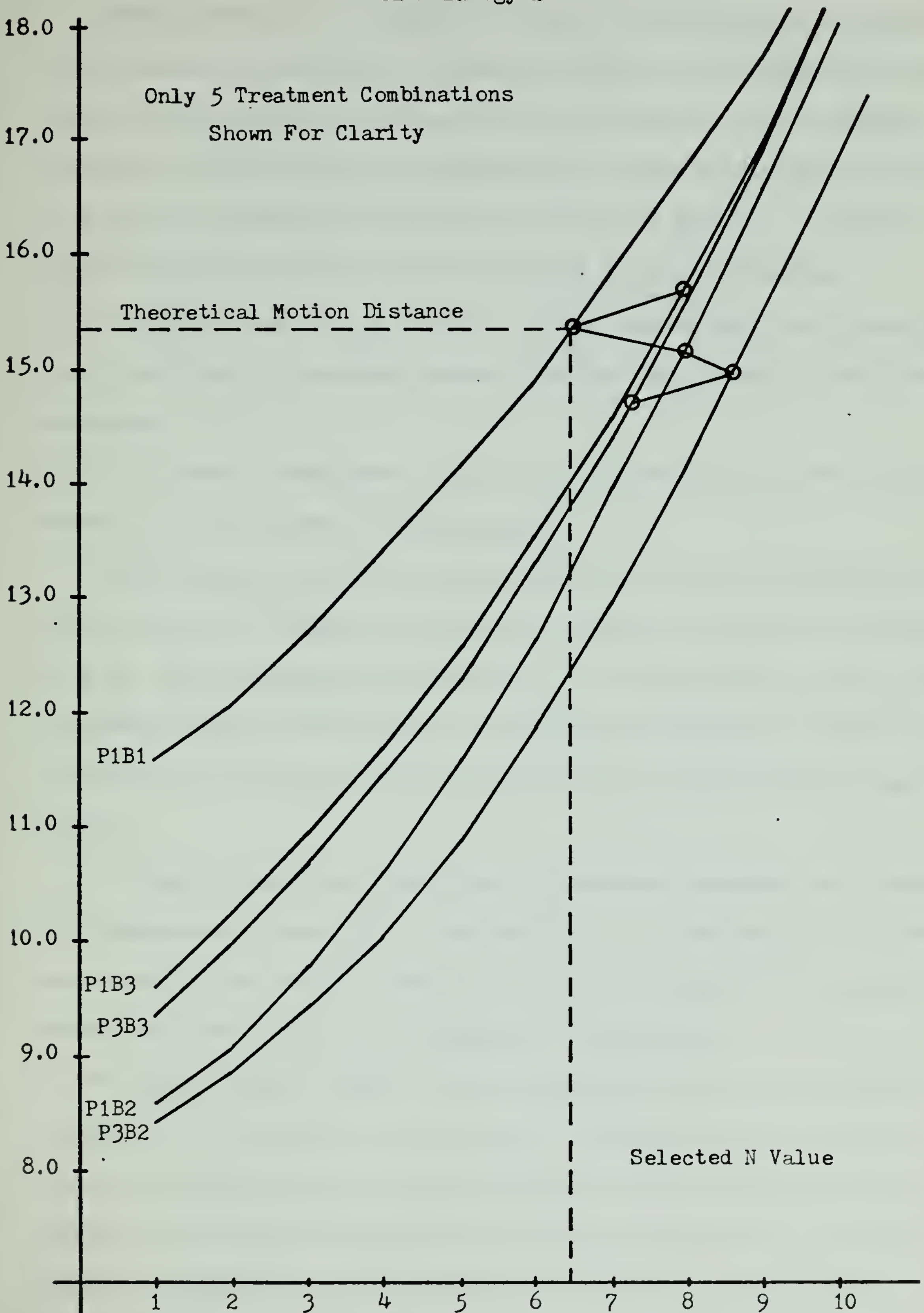
$$\frac{P_i^2}{1-P_i}$$

D. DISCUSSION OF MODELS

Methods shown in the computer programs section of this paper were used to generate expected distances for the various treatment combinations for values of N from one to ten. These values were plotted against N to obtain families of curves for all models.

Inspection of these curves revealed that only strategy 2 (the previous response model) could reasonably be said to "explain" the data for all subjects. Only for this model could one find a value of N, for each treatment combination, such that the expected distances for treatment combinations might be ranked to provide a one to one correspondence with the ranks of the response times for all subjects. As an illustration, values of N to provide such a correspondence were selected for the data provided by subject 1. This procedure is illustrated by Figure 6. These "typical" values of N, the associated mean stimulus motion, the expected

FIGURE 6. Determination of Theoretical Pre-stimulus Motion For Strategy 2



distance for the given value of N and the response times for subject 1 are summarized in Table IX.

These procedures, of course, are based on the assumption that particular treatment combinations will have an effect on the subject which will serve to change the pre-stimulus motion. Although it must be realized that the pre-stimulus motions represented in Table IX are representative of a range of values that would provide identical results, a review of Table IX provides the following intuitively satisfying results.

1. There seems to be a consistent effect across panel configurations; i.e., the values of pre-stimulus motion across panels seem to vary consistently.

2. A general trend toward an increase in pre-stimulus motion with a decrease in entropy seems to be present.

These concepts were not formally tested due to time constraints and the necessity for a formal mathematical analysis to determine the ranges of N for which the previous results hold. It would appear, however, that the general results add support to the previously mentioned assumption of variation in pre-stimulus motion across subjects and/or treatment combinations.

It should be mentioned that none of the models discussed are intended to be deterministic models for hand motion. It is believed that an adequate descriptive model for hand motion would probably combine all the models with other factors not addressed by this study.

The "last response model," however, demonstrates that a mathematical procedure can be derived which "explains" the data obtained in this experiment in terms of variation in hand motion. This would seem to lend support to the belief that the determination of hand motion paths, with the aid of adequate descriptive models of hand motion, should play a larger part in control panel design than is presently the case.

TABLE IX

THEORETICAL RESULTS FOR STRATEGY 2

	B1	B2	B3
	6.5	8	8
P1	1.69	1	1.140
	15.34	15.24	15.67
	.872	.864	.881
	5.5	8	6
	2	.85	1.13
P2	14.23	13.22	11.10
	.793	.758	.683
	6.5	8.67	7.33
	1.69	.92	1.19
P3	14.46	15.03	14.77
	.795	.828	.827
	4.9	8	7.3
	2.24	1.02	1.28
P4	13.32	14.06	13.91
	.768	.780	.770
	3	7	6
	3.67	.96	1.655
P5	12.46	11.88	12.84
	.718	.714	.723

selected N
pre-stimulus motion
expected distance
response time-S1

IV. DISCUSSION AND RECOMMENDATIONS FOR FURTHER STUDY

This study has provided a preliminary investigation of the effects of motion strategies on movement times and proposed models which might assist in the explanation of these effects. The results of the study indicate that a significant portion of previous results regarding human response phenomenon might have been explained by reference to the complexity of the actual motion paths involved. Although there were significant indications that the effect of stimulus uncertainty on response times cannot be dismissed by reference to only perceptual or cognitive processes, the study can only be regarded as exploritory in nature. Further research should be conducted to determine the effect of uncertainty on actual motion paths. Recommendations for future investigation are as follows:

1. Experiments designed to investigate actual motion distances and movement times should use touch sense buttons to confine motion to the horizontal plane in order that accurate indicies of difficulty might be obtained.

2. A more accurate means of measurement of hand motion over a surface should be developed. Cyclograph or motion picture photography do not provide the degree of accuracy required for the measurement of hand motion without advanced photo-interpretation techniques.

3. Mean responses, as used in this study, are not fully illustrative of the effects present. Future study should concentrate on responses to individual response positions and the effects of changing these positions examined on an individual basis.

4. Investigation of how an operator perceives a particular stimulus set should be conducted. The threshold of entropy at which a subject is

able to distinguish that a particular alternative is more or less likely than the remainder of alternatives should be determined.

5. Experiments should be designed and conducted to determine if the motion strategy employed by a particular operator changes with the level of entropy or remains relatively constant.

6. The inability to properly identify learning effects has often made it difficult to isolate other effects which might have been significant. Experiments designed to isolate and identify learning effects in a manual-decision task should be conducted not only to assist in the derivation of adequate descriptive models for hand motion but also to provide systems designers with additional information.

7. In addition to the basic models proposed in this study, an investigation of a model based on the assumption that an operator will always attempt to minimize his expected motion distance based on information gained on the previous N trials should be conducted.

COMPUTER PROGRAMS

The following program in BASIC was written and executed on the PDP-8 computer. The program requested the probability of occurrence of the eight integers that were to appear on the tape. It next called a subroutine which generated a random number between zero and one. This random number was converted to a random variate (I) between zero and eight inclusive. A counter associated with that variate S(I) was incremented and the proportion was checked against the desired probability of occurrence. The number was rejected if the proportion was too large and the counter decremented. An accepted number was punched on paper tape followed by a zero. All punched numbers were in ASCII code.

The random number generator used in the program was based on 12 bit word size and did not require a seed. The resultant number string had a period of 1024 numbers. [Ref. 4] Character strings were verified for randomness over various 100 character segments and across the completed string.

TAPE PRODUCTION PROGRAM

```
1 REM - PROGRAM IN BASIC TO PUNCH A SERIES OF INTEGERS
2 REM - AND ZEROS OF ANY LENGTH AND IN ANY DESIRED PROPORTION.
3 REM - TAPE IS IN ASCII AND MUST BE CONVERTED TO BCD.
4 DIM P(8),S(8)
7 PRINT "TYPE IN P1 THRU P8 ON SUCCESSIVE LINES."
10 FOR I=1 TO 8
12 INPUT P(I)
15 NEXT I
16 PRINT "TYPE IN TOTAL INTEGERS DESIRED."
17 INPUT T
25 N=10
26 M=0
27 B=0
135 LET M=INT(8*RND(0)+1)
136 S(M)=S(M)+1
145 IF S(M)/N<P(M)GO TO 175
165 S(M)=S(M)-1
170 GO TO 26
175 N=N+1
176 PTP
180 PRINT 0
185 PRINT M
186 TTY OUT
187 PRINT 0
188 PRINT M
190 IF N<TGO TO 26
192 TTY OUT
195 PRINT "THE PROPORTION OF THE INTEGERS ARE:"
198 N=N-10
200 FOR I=1 TO 8
205 PRINT S(I)/N
206 NEXT I
210 END
```

STIMULUS TAPE CONVERSION PROGRAM

Utilizing the preceding program, five tapes were punched consisting of 490 integers in ASCII code. These tapes were converted to binary code to be read by the tape reader through the use of the following machine language program executed on a CDC-160 computer.

ASCII TO BCD NUMBERS

```
0000  7500
0001  4102
0002  7203   (read 5 frames)
0003  0065
0004  6102
0005  0060
0006  2063
0007  0217   (save lower 4 bits of number)

0010  4070
0011  7500
0012  4104
0013  7303
0014  0071
0015  6102   (punch lower 4 bits)
0016  0070
0017  7101

0020  0000   (return to start)
```

TIME DATA COLLECTION PROGRAM

The following program controlled the internal clock of the PDP-8 computer and provided a time data tape at the completion of any desired number of trials.

```
1 REM -THIS PROGRAM CONTROLS CHANNELS 1 AND 2 OF THE AME-8
2 REM -MULTIPLEXER PANEL. THE TIME DIFFERENCE BETWEEN TWO SIGNALS
3 REM -CAN BE MEASURED TO 1/1000 SEC IF THE FIRST TO ARRIVE IS AT
4 REM -CHANNEL 1 AND THE SECOND AT 2. REQUIRED MAGNITUDE IS .4 V.
5 T=0
10 DIM A(500)
20 LET I=1
25 PRINT "TURN THE PAPER TAPE PUNCH ON, PLEASE."
30 PRINT "INPUT LIMIT OF NUMBER OF TRIALS TO BE RECORDED."
40 INPUT L
90 SET RATE 3,1
100 IF ADC(1)<.3GO TO 100
150 LET X=TIM(0)
200 IF ADC(2)<.3GO TO 200
210 LET A(I)=TIM(0)-X
220 LET I=I+1
222 IF I<L+1GO TO 100
225 PRINT "WANT A HARD COPY NOW? TYPE 1=YES,2=NO."
226 INPUT J\IF J=2GO TO 260
235 PRINT "OUTPUT OF ";L;"TIME INTERVALS"
238 PRINT "TRIAL #","RESPONSE TIME"
240 FOR K=1 TO L
250 PRINT K,A(K)/1000
258 NEXT K
260 RESTORE
261 PTP
262 FOR N=1 TO L
263 PRINT A(N)/1000\T=T+A(N)
264 NEXT N
265 T=T/L
266 TTY OUT
267 PRINT " THE AVERAGE RESPONSE TIME IS",T/1000,"SECONDS."
270 STOP
280 END
```

SUMMARY STATISTICS PROGRAM

The following program first requested the trials on which response errors had occurred. These trial numbers were determined by a review of the brush recorder chart. The program then read the time data tape provided and selected 400 error free responses, trimmed to eliminate obvious outliers and minimize start-up and fatigue effects, for which various summary statistics were computed and printed.

```
1 REM - PROGRAM TO COMPUTE SUMMARY STATISTICS
3 DIM T(500),E(30)
15 PRINT "TYPE IN SUBJ NR,BUTTON PANEL NR AND PROB DIST NR"
20 INPUT S
25 INPUT C
30 INPUT P
33 PRINT "TYPE IN NR OF TIMES ON TAPE"
34 INPUT N1
37 PRINT "TYPE IN THE TOTAL NR OF ERRORS"
38 INPUT E1\IF E1=0GO TO 43
39 PRINT "TYPE IN ERROR TRIAL NRS"
40 FOR I=1 TO E1
41 INPUT E(I)
42 NEXT I
43 PRINT "POSITION TIME TAPE-TYPE 1 WHEN READY"
44 INPUT O
45 PTR
50 FOR I=1 TO N1
55 INPUT T(I)
60 NEXT I
61 TTY OUT\TTY IN
62 T1=0\T2=0\T3=0
63 A=99\Z=0\B9=0
64 FOR I=26 TO N1
65 IF T(I)=999GO TO 85 \IF T(I)>2GO TO 85 \IF T(I)<.1GO TO 85
66 FOR J=1 TO E1
67 IF I=E(J) THEN T(I)=0
69 NEXT J
70 IF T(I)=0GO TO 85
71 T1=T1+T(I)
73 IF T(I)<A THEN A=T(I)
74 IF T(I)>Z THEN Z=T(I)
```

SUMMARY STATISTICS PROGRAM

```
80 T2=T2+T(I)*T(I)
82 B9=B9+1\IF B9>399GO TO 90
85 NEXT I
90 M=T1/B9
91 R=Z-A
92 V2=(B9*T2-T1*T1)/(B9*(B9-1))
93 V1=SQR(V2)
130 PRINT \PRINT \PRINT
131 PRINT "**************************************************"
132 PRINT
133 PRINT "SUMMARY FOR SUBJECT NR";S;"ON BUTTON PANEL NR";C
134 PRINT "PRESENTED WITH PROBABILITY DISTRIBUTION NR";P
135 PRINT
136 PRINT "MAX R. TIME","MIN R. TIME","MEAN R. TIME"
137 PRINT Z,A,M
138 PRINT
139 PRINT "RANGE","S. VAR.","S. STD. DEV."
140 PRINT R,V2,V1\PRINT
141 PRINT "SUMSQ","T. TIME","T. TIME SQ"
142 PRINT T2,T1,T1*T1
143 PRINT \PRINT
144 PRINT "RESULTS BASED ON";B9;"CORRECT RESPONSES"
145 PRINT "0.1<TIME<2.0 STARTING WITH TRIAL NR 26"
151 PRINT
152 PRINT "**************************************************"
153 PRINT \PRINT
199 END
```

ENTROPY PROGRAM

The following program was utilized to determine the entropy of a stimulus set of eight characters based on their relative probability. It also determined the entropy based on the relative frequency in order that an actual-theoretical comparison could be made.

```
1 REM -PROGRAM TO DETERMINE ENTROPY OF A STIMULUS SET OF
2 REM -EIGHT CHARACTERS BASED ON PROB. OR RELATIVE FREQ.
5 DIM P(8),R(8)
10 PRINT "TYPE IN P1 THROUGH P8 ON SUCCESSIVE LINES"
15 FOR I=1 TO 8
20 INPUT P(I)
25 NEXT I
30 PRINT "TYPE IN R1 THROUGH R8 ON SUCCESSIVE LINES"
35 FOR I=1 TO 8
40 INPUT R(I)
45 NEXT I
47 E=0
48 E1=0
50 FOR I=1 TO 8
51 LET X=P(I)
55 LET H1=(-1/LOG(2))*(X*LOG(X))
65 E=E+H1
75 NEXT I
80 PRINT "ENTROPY BASED ON PROB. =",E
81 FOR I=1 TO 8
82 LET X=R(I)
85 LET H1=(-1/LOG(2))*(X*LOG(X))
87 E1=E1+H1
89 NEXT I
92 PRINT "ENTROPY BASED ON REL. FREQ. =",E1
99 END
```

EXPECTED MOTION DISTANCE PROGRAMS

The program immediately following was used to determine between button distances to be used as data inputs for the next four programs which determined theoretical or expected motion distances, for the various treatment combinations, based on any mean pre-stimulus motion, for any desired strategy.

```
1 REM -PROGRAM TO DETERMINE BETWEEN BUTTON DISTANCES
2 REM -FOR ANGULAR SEPARATIONS OF 20,40,60,80,100,120,140 DEGREES
3 REM -AND ANY TWO RADIAL DISTANCES TO BE USED AS DATA INPUTS
4 REM -EXPECTED DISTANCE COMPUTATION PROGRAMS.
5 DIM R(7),D(2).
10 R(1)=.34907
15 R(2)=.69813
20 R(3)=1.0472
25 R(4)=1.39626
30 R(5)=1.74533
35 R(6)=2.0944
40 R(7)=2.44346
45 PRINT "TYPE IN TWO RADIAL DISTANCES"
50 INPUT B
55 INPUT C
60 PRINT \PRINT
65 PRINT "FOR RADIAL DISTANCES OF";B;"AND";C;"IN."
70 PRINT "AND ANGULAR SEPARATIONS OF"
75 PRINT "20, 40, 60, 80, 100, 120, AND 140 DEGREES"
77 PRINT
80 PRINT "BETWEEN BUTTON DISTANCES ARE"
85 FOR I=1 TO 7
90 A=R(I)
91 X2=B*B+C*C-2*B*C*COS(A)
93 D=SQR(X2)
94 IF I=4GO TO 97
95 PRINT D
96 GO TO 98
97 PRINT D,"RESPECTIVELY"
98 NEXT I
99 END
```

DATA LINES FOR

MOTION DISTANCE PROGRAMS

```
100 DATA 0,11,11,11,11,11,11,11,11
101 DATA 11,0,3.82,7.52,11,14.14,16.85,19.05,20.67
102 DATA 11,3.82,0,3.82,7.52,11,14.14,16.85,19.05
103 DATA 11,7.52,3.82,0,3.82,7.52,11,14.14,16.85
104 DATA 11,11,7.52,3.82,0,3.82,7.52,11,14.14
105 DATA 11,14.14,11,7.52,3.82,0,3.82,7.52,11
106 DATA 11,16.85,14.14,11,7.52,3.82,0,3.82,7.52
107 DATA 11,19.05,16.85,14.14,11,7.52,3.82,0,3.82
108 DATA 11,20.67,19.05,16.85,14.14,11,7.52,3.82,0
200 DATA 0,11,5,5,11,11,5,5,11
201 DATA 11,0,6.53,7.86,11,14.14,12.85,14.18,20.67
202 DATA 5,6.53,0,1.74,7.86,9.54,6.43,7.66,14.18
203 DATA 5,7.86,1.74,0,6.53,7.86,5,6.43,12.85
204 DATA 11,11,7.86,6.53,0,3.82,7.86,9.54,14.14
205 DATA 11,14.14,9.54,7.86,3.82,0,6.53,7.86,11
206 DATA 5,12.85,6.43,5,7.86,6.53,0,1.74,7.86
207 DATA 5,14.18,7.66,6.43,9.54,7.86,1.74,0,6.53
208 DATA 11,20.67,14.18,12.85,14.14,11,7.86,6.53,0
300 DATA 0,11,5,8,11,11,5,11,11
301 DATA 11,0,6.53,12.43,16.85,11,7.86,7.52,3.82
302 DATA 5,6.53,0,7,11.27,7.86,5,6.53,7.86
303 DATA 8,12.43,7,0,4.43,4.43,11.36,7.08,14.68
304 DATA 11,16.85,11.27,4.43,0,7.53,15.17,11,19.05
305 DATA 11,11,7.86,4.43,7.52,0,12.85,3.82,14.14
306 DATA 5,7.86,5,11.36,15.17,12.85,0,11.27,6.53
307 DATA 11,7.52,6.53,7.08,11,3.82,11.27,0,11
308 DATA 11,3.82,7.86,14.68,19.05,14.14,6.53,11,0
500 END
```

MEAN EUCLIDEAN DISTANCE

```
1 REM -PROGRAM TO COMPUTE EXPECTED MOTION DISTANCES FOR
2 REM -STRATEGY NUMBER ZERO
3 DIM P(8),D(9,9)
5 PRINT "INPUT P1---P8"
10 FOR I=1 TO 8
15 INPUT P(I)
20 NEXT I
22 B=1
24 Z=0\Y=0
25 FOR I=0 TO 8
30 FOR J=0 TO 8
35 READ D(I,J)
40 NEXT J
45 NEXT I
50 FOR J=1 TO 8
60 X=P(J)*D(0,J)
65 Z=Z+X
70 NEXT J
85 PRINT "EXPECTED MOTION DISTANCE FOR PANEL";B;"=";Z
90 B=B+1
92 IF B>3GO TO 500
95 GO TO 24
```

STRATEGY ONE

```
1 REM -PROGRAM TO COMPUTE EXPECTED MOTION DISTANCES FOR
2 REM -STRATEGY NR 1 FOR ANY PRE-STIM. MOTION DISTANCES.
3 DIM P(8),D(9,9)
5 PRINT "INPUT P1---P8"
7 FOR I=1 TO 8
8 INPUT P(I)
9 NEXT I
11 PRINT "INPUT M. P. STIMULUS NRS"
12 INPUT S1
13 INPUT S2
15 PRINT "INPUT PRE-STIM MOTION DISTANCE FOR EACH"
16 INPUT A1
17 INPUT A2
22 B=1
24 Z=0\Y=0
25 FOR I=0 TO 8
30 FOR J=0 TO 8
35 READ D(I,J)
40 NEXT J
45 NEXT I
50 FOR J=1 TO 8
51 N1=D(0,S1)/A1
52 N2=D(0,S2)/A2
53 IF D(S1,J)=0 THEN N1=1
54 IF D(S2,J)=0 THEN N2=1
60 D1=(D(S1,J)↑2+(N1-1)*(D(0,J)↑2-(D(S1,0)↑2/N1)))/N1
61 D2=D(S1,0)/N1+SQR(D1)
62 D3=(D(S2,J)↑2+(N2-1)*(D(0,J)↑2-(D(S2,0)↑2/N2)))/N2
64 D4=D(S2,0)/N2+SQR(D3)
65 L=D(S1,0)-D2\IF D(S1,J)=0 THEN D2=D2+ABS(L)
66 K=D(S2,0)-D4\IF D(S2,J)=0 THEN D4=D4+ABS(K)
68 X=(P(J)/2)*(D2+D4)
69 Z=Z+X
70 NEXT J
85 PRINT "EXPECTED MOTION DISTANCE FOR PANEL";B;"=";Z
90 B=B+1
92 IF B>3GO TO 500
95 GO TO 24
```

STRATEGY TWO

```
1 REM -PROGRAM TO COMPUTE EXPECTED MOTION DISTANCES FOR
2 REM -STRATEGY NR 2 FOR ANY ASSUMED PRE-STIM. MOTION DISTANCE
3 DIM P(8),D(9,9)
5 PRINT "INPUT P1---P8"
10 FOR I=1 TO 8
15 INPUT P(I)
16 NEXT I
18 PRINT "INPUT PRE STIMULUS MOTION DISTANCE"
19 INPUT A1
22 B=1
24 Z=0
25 FOR I=0 TO 8
30 FOR J=0 TO 8
35 READ D(I,J)
40 NEXT J
45 NEXT I
50 FOR J=1 TO 8
52 FOR I=1 TO 8
55 N=D(I,0)/A1
56 IF D(I,J)=0 THEN N=1
57 D1=(D(I,J)↑2+(N-1)*(D(0,J)↑2-(D(I,0)↑2/N)))/N
58 D2=D(I,0)/N+SQR(D1)
59 L=D(I,0)-D2\IF D(I,J)=0 THEN D2=D2+ABS(L)
60 X=P(I)*D2
65 Y=Y+X
70 NEXT I
75 Z=Z+P(J)*Y
77 Y=0
80 NEXT J
85 PRINT "EXPECTED MOTION DISTANCE FOR PANEL";B;"=";Z
90 B=B+1
92 IF B>3GO TO 500
95 GO TO 24
```

STRATEGY THREE

```
1 REM -PROGRAM TO COMPUTE EXPECTED MOTION DISTANCES FOR
2 REM -STRATEGY NR 3 FOR ANY ASSUMED PRE-STIM.MOTION DISTANCE
3 DIM P(8),D(9,9)
5 PRINT "INPUT P1---P8"
10 FOR I=1 TO 8
15 INPUT P(I)
16 NEXT I
18 PRINT "INPUT PRE-STIM. MOTION DISTANCE"
19 INPUT A1
22 B=1
24 Z=0
25 FOR I=0 TO 8
30 FOR J=0 TO 8
35 READ D(I,J)
40 NEXT J
45 NEXT I
50 FOR J=1 TO 8
51 FOR I=1 TO 8
52 N=D(I,0)/A1
53 IF D(I,J)=0 THEN N=1
54 D1=(D(I,J)↑2+(N-1)*(D(0,J)↑2-(D(I,0)↑2/N)))/N
55 D2=D(I,0)/N+SQR(D1)
56 L=D(I,0)-D2\IF D(I,J)=0 THEN D2=D2+ABS(L)
57 M=P(I)↑2/(1-P(I))
58 X=M*D2
59 Y=Y+X
60 M1=M1+M
65 NEXT I
70 M2=1-M1
75 Z=Z+P(J)*(Y+M2*D(0,J))
77 Y=0\M1=0
80 NEXT J
85 PRINT "EXPECTED MOTION DISTANCE FOR PANEL";B;"=";Z
90 B=B+1
92 IF B>3GO TO 500
95 GO TO 24
```

LIST OF REFERENCES

1. Bertelson, P., "Sequential Redundancy and Speed in a Serial Two Choice Responding Task," Quarterly Journal of Experimental Psychology, v. 13, p. 90-102, 1961.

2. Bertelson, P., "S-R Relationships and Reaction Times to New vs. Repeated Signals in a Serial Task," Journal of Experimental Psychology, v. 65, p. 478-484, 1963.

3. Blackman, A.R., "Influence of Stimulus and Response Probability on Decision and Movement Latency in a Discrete Choice Reaction Task," Journal of Experimental Psychology, v. 92, p. 128-133, 1972.

4. Digital Equipment Corporation, Basic/RT User's Manual, 1971.

5. Fitts, P.M., "The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement," Journal of Experimental Psychology, v. 47, p. 381-391, 1954.

6. Fitts, P.M. and Peterson, J.R., "Information Capacity of Discrete Motor Responses," Journal of Experimental Psychology, v. 67, p. 103-112, 1964.

7. Fitts, P.M., Peterson, J.R. and Wolpe, G., "Cognative Aspects of Information Processing: II • Adjustments to Stimulus Redundancy," Journal of Experimental Psychology, v. 65, p. 423-432, 1963.

8. Hale, D.J., "Sequential Effects in a Two Choice Reaction Task," Quarterly Journal of Experimental Psychology, v. 19, p. 133-141, 1967.

9. Hawkins, H.L., Thomas, G.B. and Drury, K.B., "Perceptual vs. Response Bias in Discrete Choice Reaction Time," Journal of Experimental Psychology, v. 84, p. 514-517, 1970.

10. Hyman, R., "Stimulus Information as a Determinant of Reaction Time," Journal of Experimental Psychology, v. , p. 188-196, 1953.

11. Kuttan, A. and Robinson, G.H., "Models of Temporal Motor Responses-Stimulus, Movement, and Manipulation Information," IEEE Transactions on Man-Machine Systems, v. MMS 11, No. 2, p. 126-128, June, 1970.

12. Lappin, J.S. and Disch, K., "The Latency Operating Characteristic: I . Effects of Stimulus Probability on Choice Reaction Time," Journal of Experimental Psychology, v. 92, p. 419-427, 1972.

13. Peeke, S.C. and Stone, G.C., "Sequential Effects in Two and Four Choice Tasks," Journal of Experimental Psychology, v. 92, p. 111-116, 1972.

14. Remington, R.J., "Analysis of Sequential Effects in Choice Reaction Times," Journal of Experimental Psychology, v. 82, p. 250-257, 1969.

15. Remington, R.J., "The Effects of Advance Information on Processing in a Choice Reaction Task," Psychonomic Science, v. 24, p. 171-173, 1971.

16. Rubin, G., Von Trebra, P., and Smith, K.U., "Dimensional Analysis of Motion: III. Complexity of Movement Pattern," Journal of Applied Psychology, v. 36, p. 272-276, 1952.

17. Scholes, E.E., Information Capacity of Discrete Motor Responses Compared for Different Directions and Amplitudes of Movement, Master's Thesis, Naval Postgraduate School, Monterey, Septebmer, 1970.

18. Simon, J.R., and Smader, R.C., "Dimensional Analysis of Motion: VIII. The Role of Visual Discrimination in Motion Cycles," Journal of Applied Psychology, v. 39, p. 5-10, 1955.

19. Stewart, J.S., Analysis of a Descriptive Model for Hand Motion Distance in a Manual Decision Task, Master's Thesis, Naval Postgraduate School, Monterey, March, 1973.

20. Thomas, M.U., "A Human Response Model of a Combined Manual and Decision Task," IEEE Transactions on Systems, Man, Cybernetics, v. SMC-3, No. 5, p. 478-484, 1973.

21. Umilta, C., Snyder, C., and Snyder, M., "Repitition Effect as a Function of Event Uncertainty, Response Stimulus Interval, and Rank Order of the Event," Journal of Experimental Psychology, v. 92, p. 320-326, 1972.

22. Whitman, C.P., and Geller, E.S., "Runs of Correct and Incorrect Predictions as Determinants of Reaction Time," Psychonomic Science, v. 23, p. 421-423, 1971.

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A preliminary investigation of the effect of actual motion distances on response times under uncertainty was performed. An experiment in which three subjects were presented with five levels of choice uncertainty and three simulated control panel configurations was conducted. Results indicated variations in response times attributable to changes in motion distance at the five percent level of significance. Explanatory models are proposed. Recommendations for future study are given.

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